

SECTION 3

PROGRAM DESIGN

The program design of the bioreactor project has been outlined in the Quality Assurance Project Plan for Landfill Bioreactor Studies (included herein as Appendix ?). The Outer Loop project is under joint investigation by the EPA and Waste Management, Inc., through a five-year Cooperative Research and Development Agreement (CRADA).

The Outer Loop Landfill is owned and operated by Waste Management, Inc., and has been used for waste disposal for approximately 35 years. The project's two multi-year studies are underway at the site, including the Facultative Landfill Bioreactor (FLB) study, and an Aerobic-Anaerobic Landfill Bioreactor (AALB) study. At Outer Loop, operation variables differ by separate and distinct landfill units, each composed of two paired (duplicate or replicate) cells.

In contrast to other bioreactor research, these demonstrations are large-scale research efforts at a full-scale operational landfill. The FLB study covers approximately 26.4 acres (total) in paired landfill cells; these cells are four to six years of age. The AALB study covers 12 acres (total) in paired one-year old landfill cells. The FLB cells were retrofitted for bioreactor operation whereas the bioreactor infrastructure in the AALB cells is constructed as waste is added. A separate unit of paired cells, containing approximately two to three year old waste, is used as the control for the FLB and AALB studies. Table 3.1 provides a summary of the cells under investigation.

TABLE 3-1 SUMMARY TABLE OF CELLS UNDER INVESTIGATION

LANDFILL UNIT	SUBUNIT	SUBCELL	TITLE	OPERATIONAL VARIABLES
5	1	A	FLB	Addition of nitrate/nitrite enriched leachate from the SBR Unit through series of retrofit surface trenches.
5	2	B	FLB Duplicate	Addition of nitrate/nitrite enriched leachate from the SBR Unit through series of retrofit surface trenches.
5	1	B	FLB	Addition of nitrate/nitrite enriched leachate from the SBR Unit through a series of retrofit surface trenches. Although subject to the FLB operation, participation in the study is restricted to a limited section of the sampling strategy and landfill gas collection.
5	2	A	FLB Duplicate	Addition of nitrate/nitrite enriched leachate from the SBR Unit through a series of retrofit surface trenches. Although subject to the FLB operation, participation in the study is restricted to a limited section of the sampling strategy and landfill gas collection.
7	3	A	CONTROL	Operated as a traditional Subtitle D landfill Unit.
7	3	B	CONTROL Duplicate	Operated as a traditional Subtitle D landfill Unit.
7	4	A	AALB	Air injected through a series of pipes constructed on the surface of each lift during waste placement, for a period of 30-60 days per lift. Moisture, primarily leachate, added after aeration is complete through the piping network.
7	4	B	AALB Duplicate	Air injected through a series of pipes constructed on the surface of each lift during waste placement, for a period of 30-60 days per lift. Moisture, primarily leachate, added after aeration is complete through the piping network.

LANDFILL UNIT DESCRIPTIONS

MSW Landfill Control (Control)

The conventional MSW landfill Unit 7.3 has been designated as the Control for the project. Unit 7.3 has been operated as a conventional RCRA Subtitle D landfill with no moisture or air addition, but is monitored and sampled in a similar manner to the FLB and AALB units to provide comparison data for the study. The Unit is located in the southeast corner of Unit 7. Unit 7 is located in the western portion of the Outer Loop Landfill complex, as shown on the Project Site Location Map in Figure 2-1.

Unit 7.3 consists of two-paired landfill cells, 7.3A and 7.3B. The Control unit is directly adjacent to Unit 7.4, which is the Aerobic-Anaerobic Landfill Bioreactor (AALB) portion of this study. A barrier layer is installed between units 7.3 and 7.4 (the Control and AALB) to prevent migration of leachate/moisture quantities, as well as landfill gas. This barrier layer consists of an impermeable clay along with an additional layer of permeable tire chips (to allow preferential movement of moisture and/or landfill gas at the unit edge).

The Control cells for this research project were selected as the best nearby representation of a Subtitle D waste mass. Prime attributes includes no past or ongoing moisture addition to the waste, and the filled areas had standard vertical landfill gas wells, common to the majority of U.S. Subtitle D sites. The Control area was originally filled starting in 1998. At the start of the project in 2001, solid waste in the control cells was nearing three years old, while the comparison bioreactor Unit 5, was approximately five years old, and the Unit 7.4 was at age zero.

In early 2001, WMI began processing a permit application for a facility horizontal expansion. In part, due to a recent federal rule by the Federal Aviation Administration about landfill siting and required distances from airports, the approval for the expansion was delayed for several quarters. Currently, this expansion is scheduled for Summer 2004.

The permit delays resulted in a significant decrease in available space to dispose of solid waste which, in turn, impacted the construction of Unit 7.4. Specifically, to complete the “as Built Bioreactors” in cells 7.4A and B, the vertical height for the remainder of Unit 7 (including the Control) had to be raised to final grades before the end of the project. At the beginning of the project, the initial volume in cell 7.3A was 822,387 in-place cubic yards and in cell 7.3B, 692,139 in-place cubic yards (ipcy). Over the remaining life of the project there will be a slight increase in both of these cells in order to bring the cells to final grade and allow for the completion of the “as Built” cells on the western slopes (see overall site plan given in Figure 2-1). The net result will be an increase of 7.3 percent in ipcy for cell 7.3A and 10.7 percent for cell 7.3B. Final grades are illustrated in Figure 3-1.

Volume changes in the Control are documented quarterly. Figure 3-2 illustrates the grading of the Control unit from September 1998. Below, in Table 3-2, is the surveyor’s geometric calculation of airspace in place at various times over the life of the project

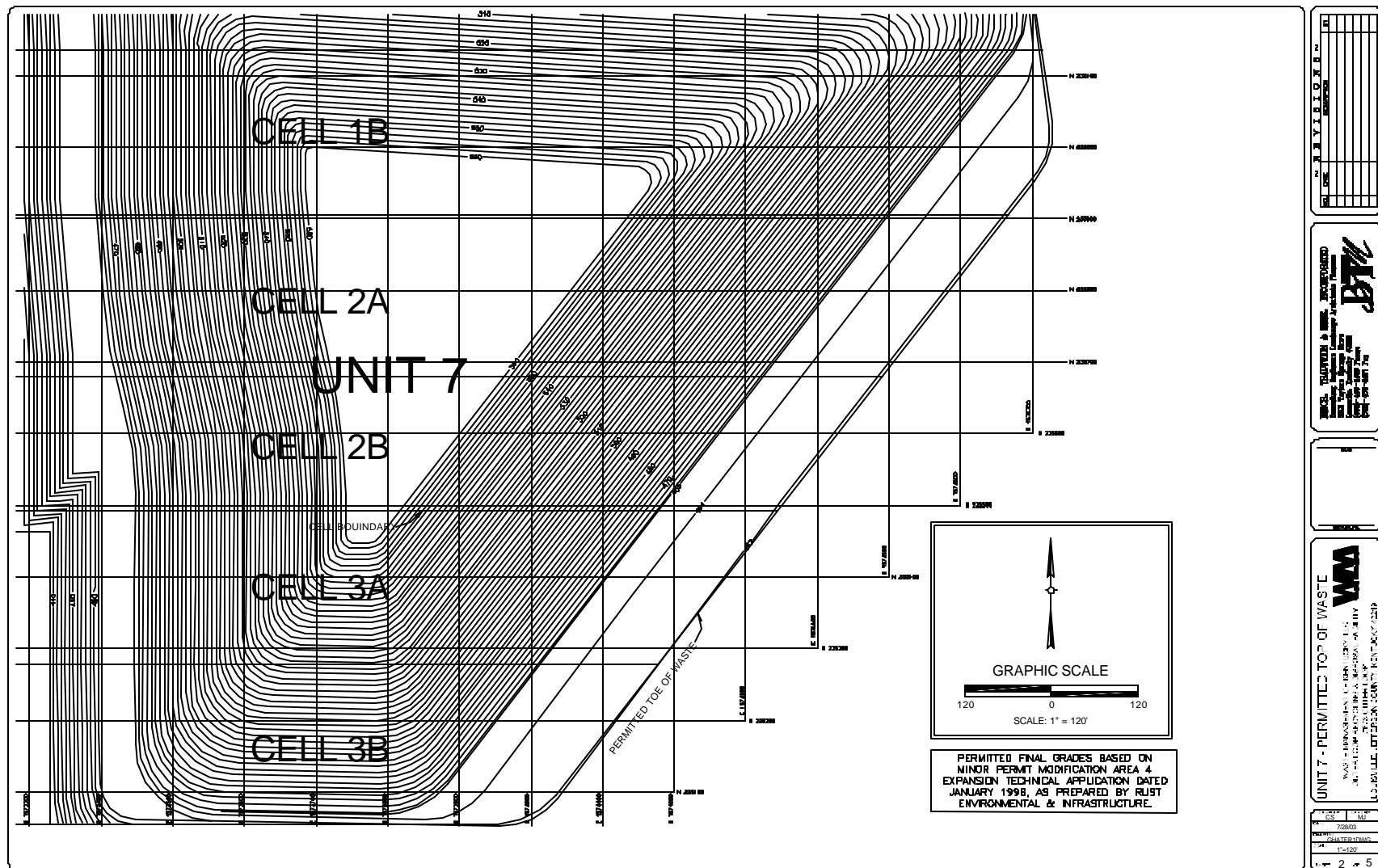


Figure 3-1. Final Projected Grade of Control Unit

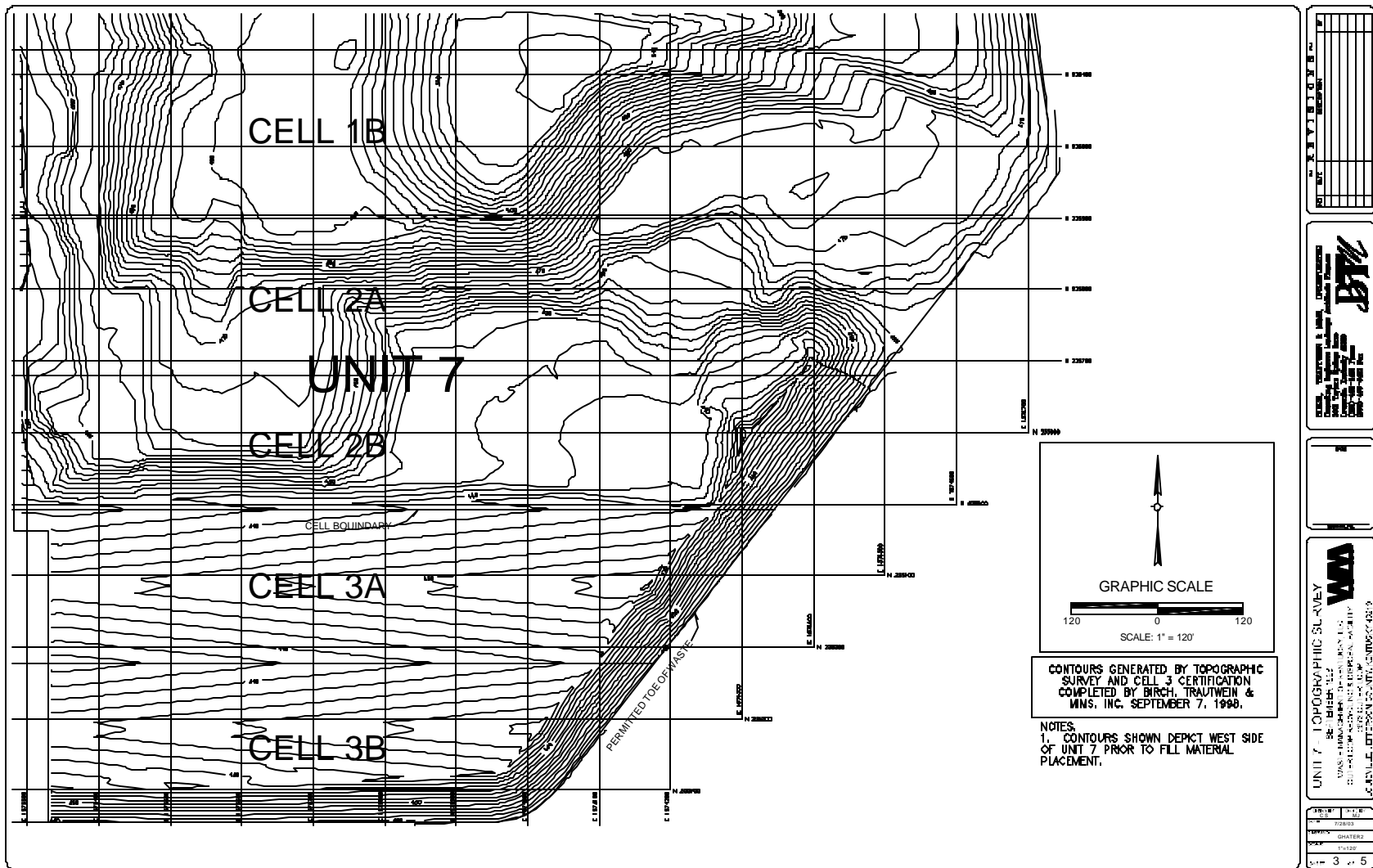


Figure 3-2. Grade of Control Unit, September 1998

TABLE 3-2 IN-PLACE CUBIC YARDS IN CONTROL OVER TIME

DATE	7.3A	% CHANGE	7.3B	% CHANGE
Fall 2001	822,387		692,139	
April 28, 2003	856,873	4.1%	730,021	5.4
Aug. 8, 2003	874,514	6.3%	747,662	8.0
Final, winter 04	882,908	7.3%	766,310	10.7

Concurrent with the waste additions to the Control, settlement plates are being placed on the slopes that are now being filled and three landfill gas wells may be added (the LFG wells are scheduled for Fall 2004). The settlement plates and new LFG wells will be monitored as part of the Control portion of the project to assess the benefits/impacts of this new loading on the Control cells.

Resampling of the waste mass is scheduled for 2004. For the control, the 1998-2000 waste mass and the 2003 – 2004 mass will be tracked separately. This may yield subsequent project comparisons between portions of the Control and the AALB that are of essentially the same age.

Leachate quantities from the Control will be affected from the opening of the southeast long-term cover until at such time the cell is re-covered. This opening is scheduled for about August 2003 until Spring 2004. During this period, the project may observe related changes in leachate cell volume and possibly leachate quality on account of periods of heavy precipitation.

FLB Process Description

Landfill Unit 5 has been designated the FLB for this portion of the study. The FLB Unit 5 is located in the northern portion of the Outer Loop Landfill complex, as shown on the Project Site Location Map in Figure 2-1. Unit 5 consists of four separate landfill cells, 5.1A, 5.2A, 5.1B and 5.2B, with Unit 5.1A (the most southern cell) and Unit 5.2B (the most northern cell) being the two primary FLB cells in the study.

Landfill Unit 5 began accepting waste in July 1995, a total of approximately 1,930,825 tons of waste was in place by October 1997. Retrofit activities took place in March through May 2001. Retrofitting the landfill unit was conducted by modifying it to become a bioreactor cell. Retrofit activities included installing trenches, moisture distribution and gas collection piping, thermocouples, and Oxygen Reduction Potential (ORP) probes. Figures 3-3 and 3-4 show the north-south cross-section and east-west cross section, respectively.

A series of horizontal trenches were installed up to 18 feet below the surface in Cells 5.1 and 5.2. Each trench contains a perforated pipe and was back-filled with a permeable material. The trenches were spaced approximately 60 feet apart. Six vertical gas extraction wells (twelve total) also were constructed in cells 5.1 and 5.2. The gas wells serve a dual purpose of collecting landfill gas and penetrating layers of soil cover placed during landfilling. Probes for measuring temperature and oxidation-reduction potential (ORP) were installed during vertical gas well installation in 2000. Additional thermocouples and ORP probes were installed during the 2001 retrofitting with the gas collection and liquid distribution piping. These probes were

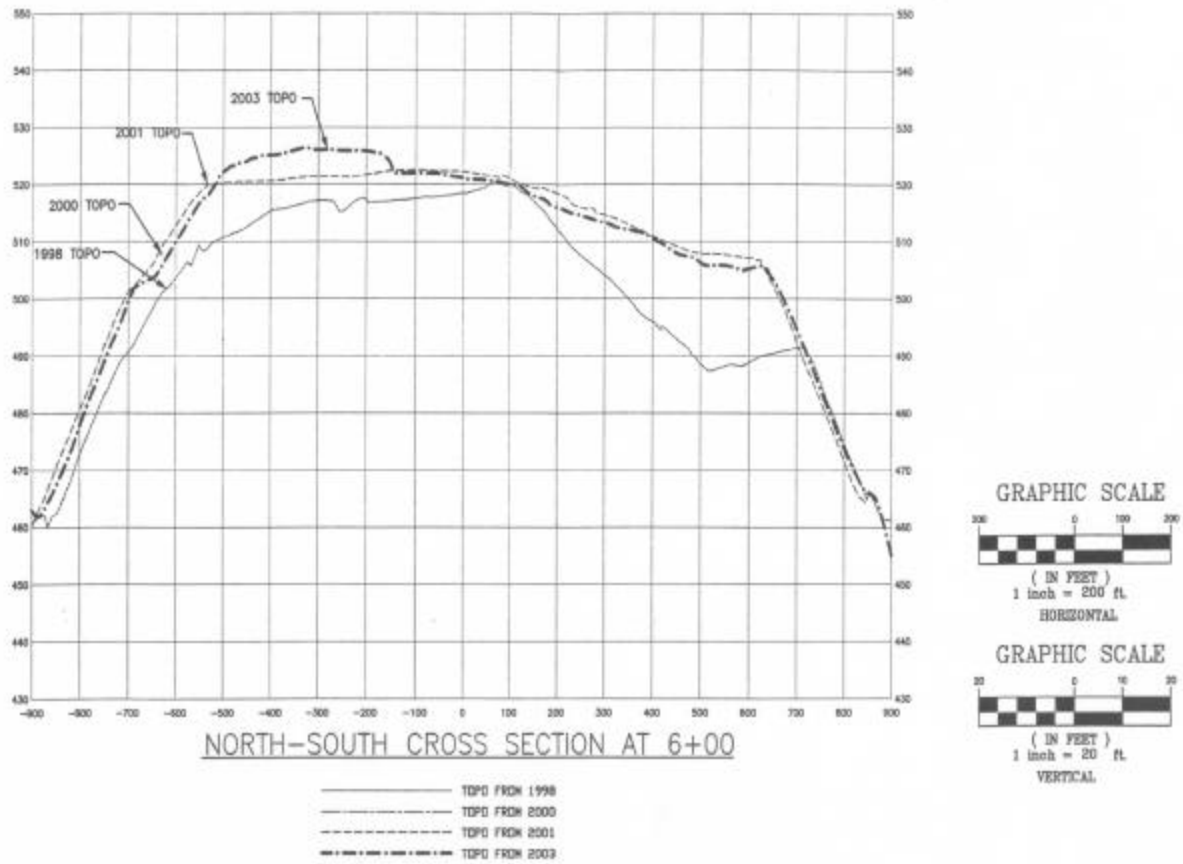


FIGURE 2

Figure 3-3. Unit 5 North-South Cross Section

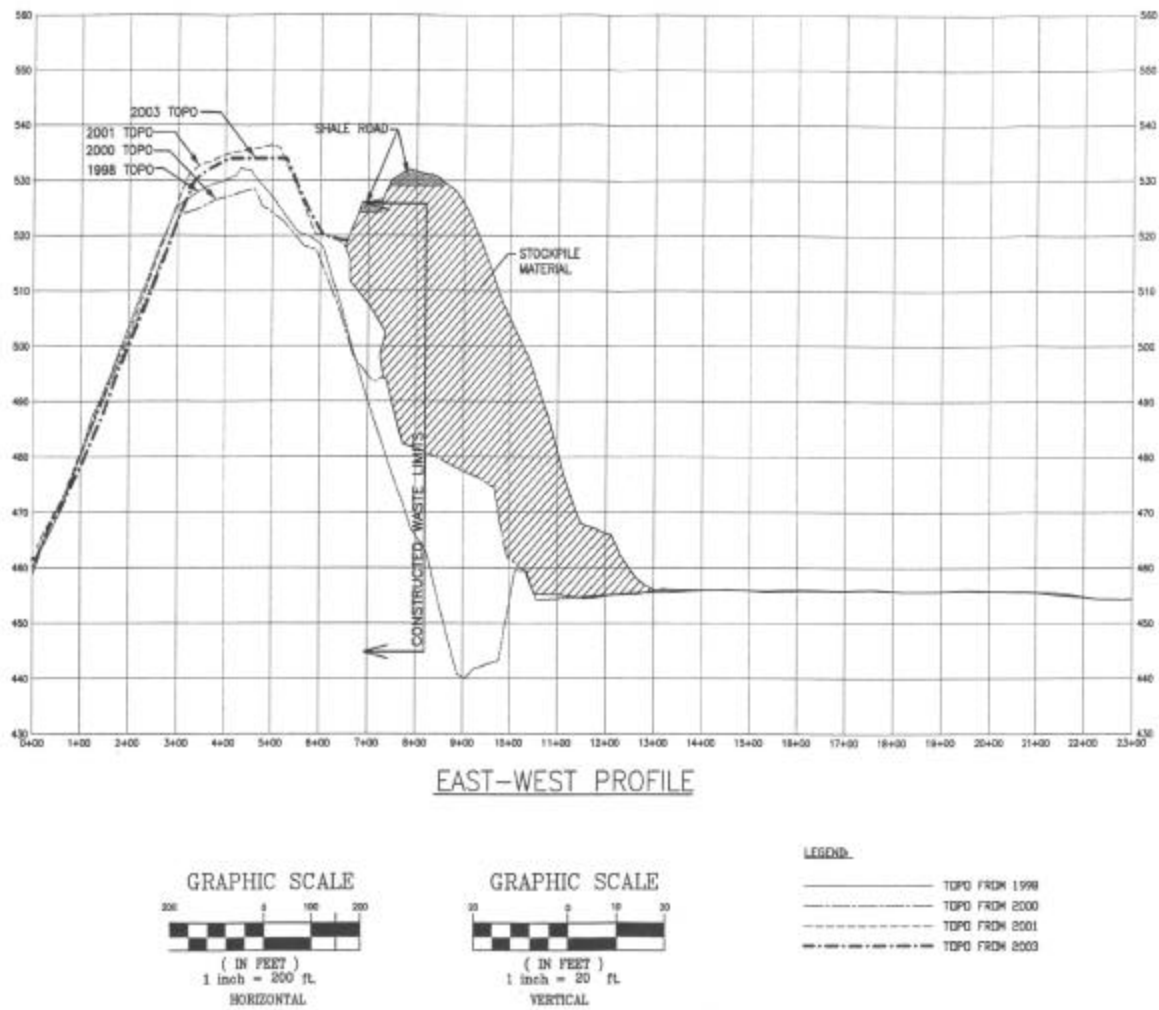


FIGURE 3

Figure 3-4. Unit 5 East-West Cross Section

placed in the trenches. Similar installations were made for the 7.3A and 7.3B Control cells. Figures 3-5 and 3-6 show the trenching system as well as the gas extraction well temperature probe placement.

Changes in the state of degradation in the waste mass, for example, the impact of nitrified effluent applied to the landfill in Unit 5 and subsequent denitrification, should impact the overall mass balance of nitrogen as the nitrate is converted to nitrogen gas. The data collected for COD, BOD, ammonia nitrogen, nitrite-nitrogen and nitrate-nitrogen, as well as leachate quantification are examined in Section 5-Results.

AALB Process Description

Landfill Unit 7.4 has been designated the AALB for this portion of the study. Unit 7.4 is located in the southwestern portion of landfill Unit 7. Landfill Unit 7 is located in the western portion of the Outer Loop Landfill complex as shown on the project site location map in Figure 2-1.

Unit 7.4A began receiving waste in July 2001 and 7.4B began receiving waste in September 2001. Units 7.4A and 7.4B are currently accepting waste, with approximately 959,993 cubic yards of waste in place as of March 2003.

Construction of the AALB features occurred concurrently with waste placement in Units 7.4A and 7.4B. The base layer of the unit consists of an initial, uncompacted layer of waste which serves as liner protection. AALB cells 7.4A and 7.4B were constructed in 15-foot vertical lifts. This shallow lift system results from grading waste to promote homogenization of the incoming solid waste. As each lift was completed, water was added to increase the moisture content of the waste. Perforated pipes then were placed at regular intervals across the top of the waste. The pipes were covered with a permeable media. Each lift of piping was then connected via a common manifold. The next lift of waste was then placed over the installed piping, and the construction sequence was then completed for each successive lift of waste. The buried piping system serves the three-fold purpose of aeration, moisture distribution, and gas collection. Figure 3-7 shows the end view of the north-south cross section of Unit 7.

As of April 2003, waste was no longer being accepted into the AALB study unit. Waste will be added again starting in late 2003 or early 2004.

TYPICAL LATERAL CROSS SECTION

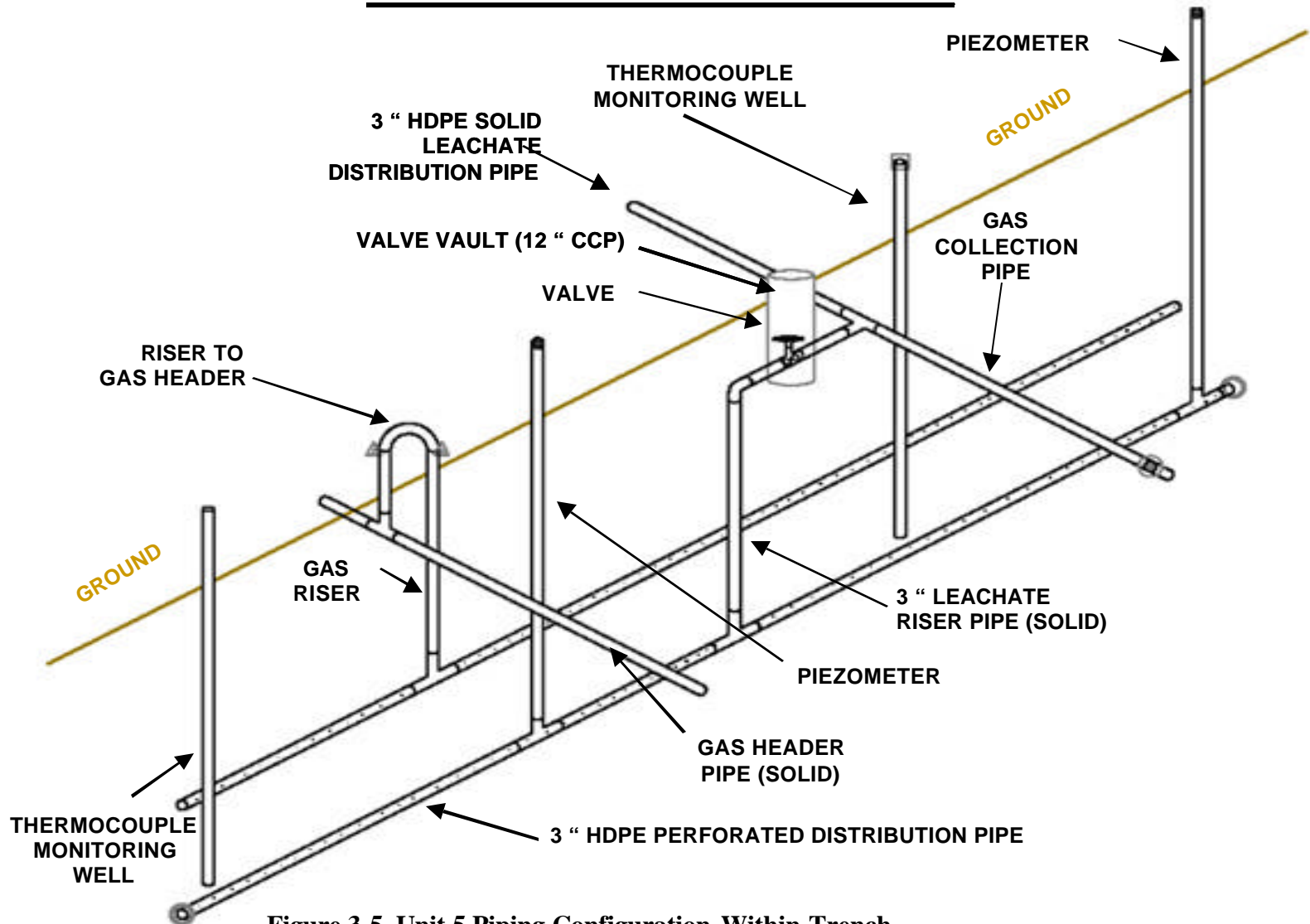


Figure 3-5. Unit 5 Piping Configuration Within Trench

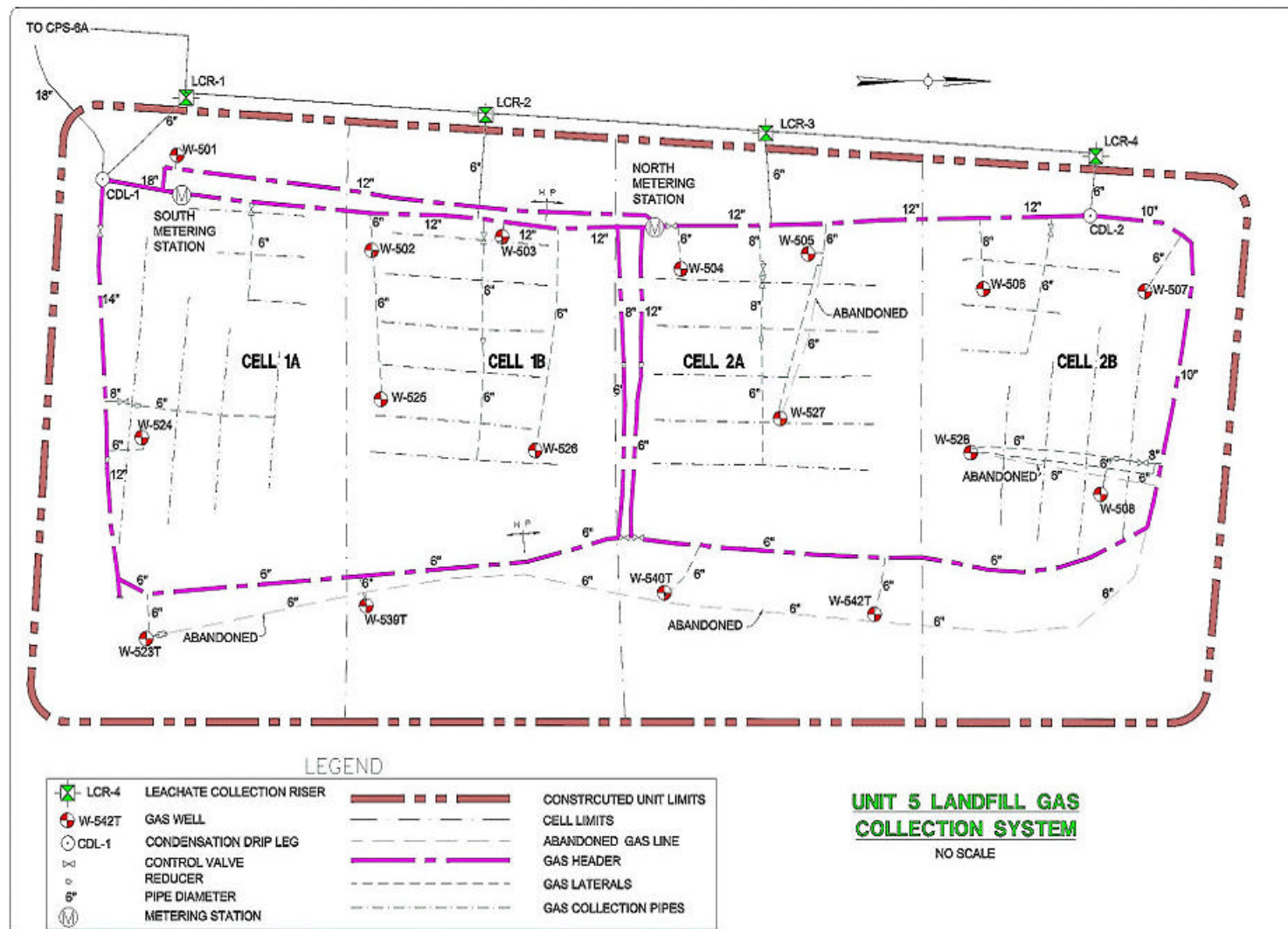


Figure 3-6. Unit 5 Gas Extraction Well and Temperature Probe Placement

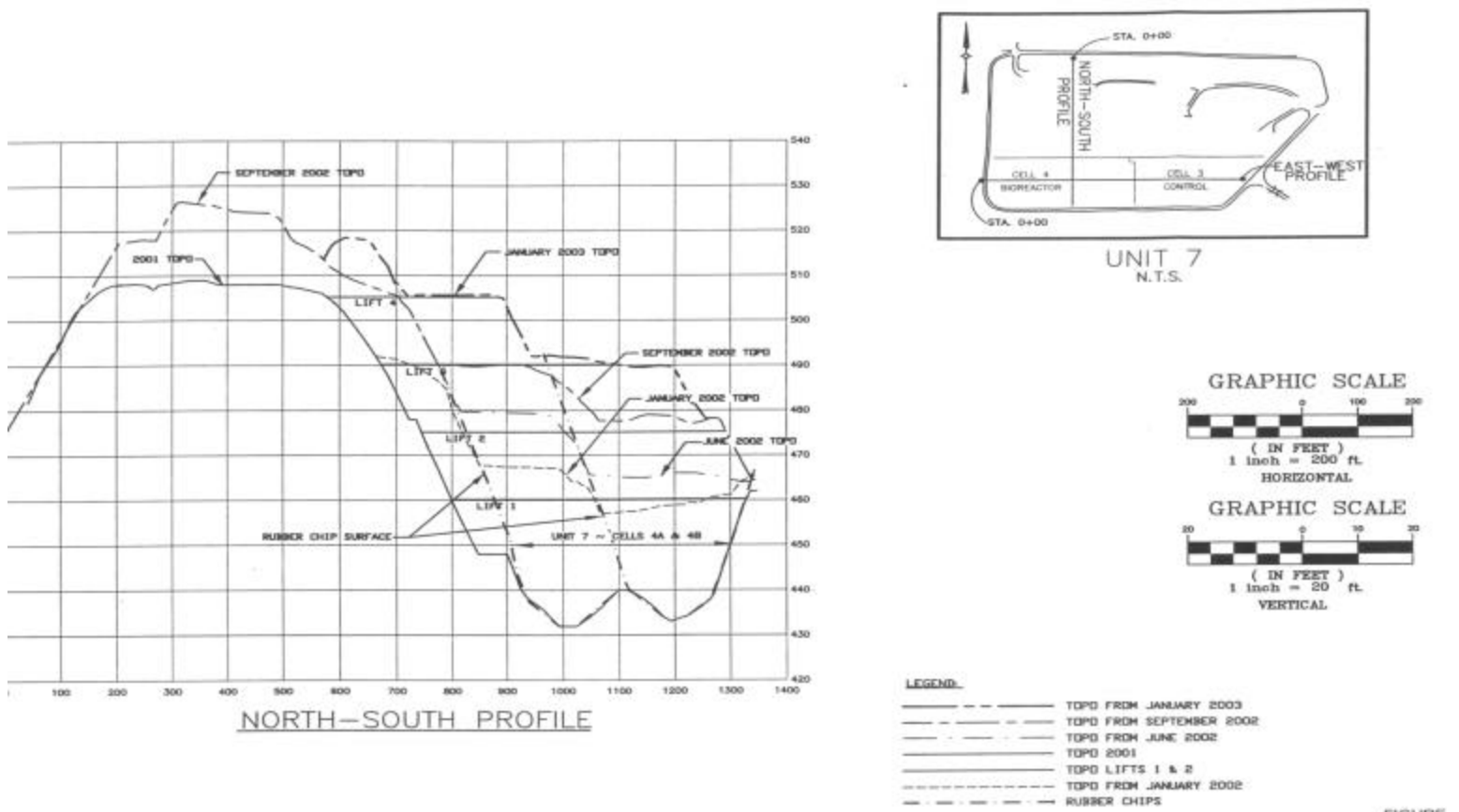


Figure 3-7. Unit 7 North-South Cross Section

BIOREACTOR TREATMENT STRATEGIES

Moisture Addition

Moisture addition is made to the FLB and AALB cells and not the Control cells. This moisture is primarily recirculated leachate, along with various other on-site moisture sources. For the AALB, the recirculated leachate is not treated prior to return to the waste mass.

For the FLB, recirculated leachate is treated through use of a chemolithotropic bacteria to take NH_4^+ to NO_3^- in the aerobic Sequential Batch Reactor (SBR). In concept, the denitrifying bacteria under anaerobic conditions in the landfill will use the NO_3^- as a terminal electron acceptor to form both N_2O and N_2 gasses. This nitrified leachate is introduced to the waste through the series of horizontal trenches that were installed in cells 5.1 and 5.2. The treated SBR effluent is monitored on a monthly basis for COD, BOD, ammonia–nitrogen, nitrite–nitrate nitrogen and phosphorous.

The treated leachate is pumped to a holding tank and distributed to the trenches via a force main and manifold for distribution to the FLB. Moisture sources other than the leachate, such as water from Outer Loop underdrain or sedimentation pond, or other liquid waste streams as permitted by regulation, may be used to augment the supply of leachate. These liquid sources are monitored in the same way as the SBR effluent in order to follow nitrogen dynamics. Moisture volumes additions are performed by the landfill operator and are dependent, in part, on precipitation, moisture levels in the waste, and other factors. Operator judgment is used as necessary to achieve and maintain the in-place waste at desired moisture levels, as discussed in Section 6. .

Air Addition

Aeration in the AALB study also is designed to achieve accelerated stabilization of solid waste. The purpose of the aeration process is to biodegrade organic matter in the waste in an initial aerobic composting stage prior to establishing the typical anaerobic conditions. Theoretically, by rapidly degrading the organic waste, the acid or lag phase (see below) of the landfill degradation process will be reduced significantly, resulting in a more rapid progression toward methane generation in the anaerobic stage. In addition, the accelerated degradation of easily degradable organic waste may result in improved leachate quality and a reduction in gaseous non-methane organic compounds (NMOCs) emissions. Aerating the uppermost lifts of the landfill should also establish conditions conducive to the biological oxidation of methane gas that is generated in the lower anaerobic lifts, thus reducing methane emissions. During and after aeration, moisture is added to control the temperature in the waste.

TIMELINE AND DATA COMPARISONS

Landfill units are filled sequentially (placement of waste in a particular cell is only initiated after the current waste-receiving cell is completely filled), therefore individual units in this study are not directly comparable with respect to time. The Control cells provide an adequate treatment reference by considering them as temporally offset from the treatment cells. For example, consider the comparison between FLB cells and the Control. As mentioned, FLB

waste is generally four to six years old and control waste is about two to three years old. In three years, Control waste will be approximately the same age as present-day FLB waste. Therefore, Control samples collected three years following the initiation of the FLB treatment should be comparable to FLB cell data from when leachate was first introduced. Figure 3-8 provides a timeline for comparison of significant events for this project.

FIGURE 3-8. TIMELINE OF EVENTS AT OUTER LOOP

	1995	
	JULY	FLB A & B start receiving waste
	1996	
	1997	
	OCT	FLB stopped receiving waste
	1998	
Control 7.3A&B start receiving waste	NOV	
	1999	
	2000	
	JUL	FLB A&B start receiving waste
CRADA approved and signed	OCT	
	2001	
	JAN	State approval received for FLB retrofit
FLB retrofit began	MAR	FLB stopped receiving waste
FLB retrofit complete	MAY	SBR Treatment construction began
AALB A starts receiving waste	JUL	
Aeration commenced within 30 days of completing each new lift	SEPT	AALB B starts receiving waste Aeration commenced within 30 days of completing each new lift
State approval received for AALB construction	OCT	
	2002	
	JAN	SBR Treatment Unit complete
	MAR	Addition of liquids to FLB Unit began
Addition of liquids to FLB Unit ceased	SEPT	
	2003	
	SEPT	First interim report due for submission

CRITICAL AND NON-CRITICAL PARAMETERS

Landfilled waste typically progresses through five phases of degradation, including: (1) adjustment or acclimation; (2) transition; (3) acidogenesis; (4) methanogenesis; and (5) maturation (Reinhart and Townsend 1998). This degradation process can be collectively considered as waste stabilization. At any given time, landfill cells may be characterized as experiencing one of the above phases. But because waste is deposited in a landfill cell over time (months to years), waste-stabilization phases tend to overlap and sharp boundaries between phases are not typical.

1. **Acclimation.** During acclimation, microbial populations are in a state of adjustment. Waste moisture tends to increase and available oxygen is consumed during this phase. The atmospheric-oxygen supply to the buried waste is diffusion limited and outpaced by the oxygen demand of bacterial respiration; consequently the concentration of oxygen in the landfill cell begins to decrease.
2. **Transition.** In the transition phase, conditions turn anaerobic as the available oxygen is consumed through the metabolism of readily degradable wastes. Complex organic matter is broken into simpler forms (e.g., organic acids) and energy that is not captured by cells during respiration is given off as heat. Waste and leachate temperature concomitantly increase during organic-matter degradation. Other respiration by-products (carbon dioxide and volatile organic acids) begin to increase in leachate.
3. **Acidogenesis.** During acidogenesis the accumulation of volatile organic acids reaches its peak due to metabolism and fermentation of organic matter. The increase in chemical oxygen demand and biochemical oxygen demand indirectly reflects this increase in degradable metabolites. In addition, the high concentration of acids increases hydrogen ion activity, reflected by decreased waste and leachate pH. In the near absence of oxygen, metabolism shifts to anaerobic bacteria capable of utilizing alternate electron acceptors (e.g., nitrate and sulfate).
4. **Methanogenesis.** In the methanogenic phase, the supply of most electron acceptors is exhausted. Methanogenic bacteria ferment organic acids to methane and carbon dioxide while other methanogens utilize CO₂ as their terminal electron acceptor. Consequently, gas (methane and CO₂) volume and production rates increase. Anaerobic respiration is a proton-consuming process and this is reflected by an increase in pH values in the waste and leachate.
5. **Maturation.** The maturation phase represents the end-point of landfill settlement (surface GPS measurements). The overall conversion of complex wastes to leachable organic acids and gaseous products also serves to reduce the waste volume and organic solids and to increase waste density. Maturation occurs when degradable organic matter, and consequently microbial growth, is limited. This is reflected by decreases in the biochemical methane potential and gaseous metabolic by-products methane and CO₂. Concentrations of organics in leachate remain steady but at substantially reduced levels relative to earlier phases.

It is expected, that the bioreactor treatments will increase the rate of transition through the various phases relative to the control. It is further expected that this enhanced transition to stabilized waste will be discernable with trend analyses.

The parameters selected for study for this project were divided into two basic groups termed critical and non-critical. The rationale for the parameter selection and grouping was based firstly on what parameters are currently monitored in conventional Subtitle D landfills and are useful indicators for optimal daily running of a landfill. Additional parameters were selected for research interest, based on previous landfill bioreactor study findings, ultimately cost evaluation also played a determining factor in the selection.

The critical measurements were selected as the best means to capture aspects of waste stabilization over time. The extend of parameters selected was designed to meet the initial objective to determine which parameters should be monitored in addition to those already monitored in conventional Subtitle D landfills, should either of these models be adopted as a standard method for landfill operation. Ultimately it is anticipated that a combination of the critical and non-critical grouped parameters will provide sufficient information over the life of the project to understand and evaluate these bioreactor designs, as compared with conventional landfilling techniques, and meet the objectives set for this research project.

TREND MONITORING

Settlement

Settlement of the fill is monitored quarterly through GPS measurements of elevation as an indication of biological stability. The numerous GPS sample points provide a data set with which to evaluate waste settlement. In addition to GPS measurements and survey data, settlement plates have been installed to measure settlement and stability of the landfill test cells.

Pneumatic settlement cells and conventional settlement plates were installed to help define the limits of the test cells in areas they are laid over existing waste. It is expected that the pneumatic settlement cells will provide accurate measurement of settlement at depths greater than that of conventional settlement plates in operating landfills.

A total of eight settlement plates were installed in Unit 5; seven of these plates remain in place to date. Unit 7.4 currently has two settlement plates in place. A total of three plates have been located in the control area to measure the settlement rates as a comparison. The top elevation of each plate was surveyed prior to the start of liquid injection.

Leachate

Leachate is collected from each of the cells in the study. The design of the landfill units (paired cells) is such that, with exception of Unit 5, each cell is separated from the surrounding cells. With respect to Unit 5, 1,000 feet of waste separate sample locations for cells 5.1A and 5.2B. The median of the two treatment cell observations from each sampling event will be calculated, resulting in a single time series for each treatment and control. These time series are used to assess trends, or lack thereof, for those characteristics and analytes measured in the leachate.

Municipal Solid Waste

Incoming solid waste is weighed on scales as it enters the landfill and prior to disposal in certain cells. In addition to weight, waste volume is calculated based on quarterly survey events using global positioning system on a fixed GPS grid. In addition, changes in surveyed slope points and an annual aerial photometric survey are used to supplement volume calculations. Waste composition is recorded according to the type of incoming waste: municipal solid waste; special waste; solidification waste; biosolids; asbestos; and construction and demolition debris.

Along with the two-dimensional analyses outlined for the leachate and the landfill gas, three-dimensional analyses are done for the municipal solid waste. If the treatment is more effective at one depth than another, incorporating depth into the MSW data assessment may identify it.

Settlement and fill are monitored quarterly through GPS measurements of elevation as an indication of stability. The numerous GPS sample points provide a data set with which to evaluate waste settlement. Specific techniques on the employed technique of GPS surveying are provided in Section 4.

Landfill Gas

Gas sampling for CO₂, O₂ and CH₄ are performed weekly. NMOC, HAPs and methane surface emissions monitoring are performed quarterly. Similar to leachate, gas sampling occurs at one point per cell where the gas extraction wells come to the collection point. The gas extraction wells are located systematically, approximately equidistant from one another. The number and location are selected to be representative of the cell. A description of the gas sampling procedure and analyses are given in Section 4.

Methane Surface Emissions: Regulatory Monitoring

Surface emissions are monitored on a quarterly basis in accordance with the requirements specified by the New Source Performance Standards (NSPS) and Emission Guidelines (EG) for municipal solid waste landfills in 40 CFR 60.755. Methane concentrations are measured within 5 to 10 cm (2 to 4 in.) of the landfill surface using the CEC-Landtec SEM 500. Methane surface concentrations are monitored around the perimeter of the collection area along a pattern that traverses the landfill at 30-meter intervals and where visual observations indicate elevated concentrations of landfill gas.

Fugitive Gas Emissions Study

Fugitive gas emissions are those gaseous emissions that are not captured through the engineered LFG collection system. Optical remote sensing (ORS) was used to evaluate fugitive gas emissions (primarily methane) for the FLB, AALB, and Control study units. At least three rounds of fugitive gas emissions testing are to be conducted at this site to estimate impacts on fugitive emissions from landfill bioreactors when compared to controls. Three rounds of testing will be completed by Fall 2003, with final results available in the Spring 2004. The most recent available set of measurements is presented in Appendix E.